

Analysis of the Influence of Machine Tool Deformation on Die Surface Deformation based on Workbench

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Abstract

With the development of the automotive industry, the competition in the automotive market is getting fiercer. Major automakers are striving to develop new technologies and introduce new models to attract more consumers and expand the market. With the introduction of new models, consumers' requirements for vehicle safety, aesthetics, etc. are improving. Therefore, when designing metal stamping parts such as interior and exterior body covers, automakers must consider these factors. To improve the efficiency of automotive cover mold design, it is necessary to consider the factors that affect the deformation of the die surface during the mold design stage. This article mainly uses Workbench finite element simulation to explore the influence of punching machine deformation on the die surface of the mold.

Keywords

Die Face Design; Finite Element Simulation; Machine Deformation.

1. Introduction

In the processing of automotive cover parts, stamping molds play a crucial role. Traditional stamping mold design has formed its own design specifications and accumulated certain experience in the process of design improvement. Currently, the interior of drawing molds generally adopts a "grid-type" structure as the load-bearing structure [1]. In the process of mold design, a large safety threshold is generally adopted, which leads to a lack of attention to the actual stress and deformation of the mold structure [2-4]. Generally speaking, the materials used to make molds have high strength and stiffness, and deformation can be ignored. Molds are generally regarded as rigid bodies. However, in actual production, large automotive cover part molds may be subjected to forces of several hundred or even thousands of tons on the press, which can cause the mold to become a dynamic elastic body during the actual stamping process. When the mold surface is subjected to pressure, slight deformation occurs, which affects the conformity rate between the punch and die during stamping. In addition, during the drawing process, the material will experience a certain amount of thinning due to stretching, which can lead to the designed surface not matching well with the stamping parts, affecting the quality of the stamping process [5,6].

1.1 Research Status

At present, the research on the elastic deformation of molds is mainly qualitative, and it is impossible to accurately compensate the mold surface. The treatment of the mold surface generally relies on experience, and more in-depth quantitative research is needed [7]. Choi [8] and Yu Qiang [9] considered the influence of mold elastic deformation on forming, and it was found that considering mold elastic deformation can more accurately predict sheet metal forming and springback. Firat [10,11] conducted structural analysis of a mold, and the results showed that when the forming force was 676 tons, the maximum deformation and equivalent stress of the punch were 0.86mm and

509MPa, respectively. To improve the plastic deformation area, the wall thickness was increased from 4mm to 6mm, and the maximum deformation and equivalent stress changed to 0.61mm and 348MPa, respectively, with significant improvement. Del Pozo [12] scholars designed a method to compensate the mold surface during the design stage to improve the first-time mold closing rate. This method directly analyzes dynamic strength of the mold, which is difficult to model and requires a long calculation time. Zhang Guibao [13] proposed a coupled analysis method for stamping die structures based on sheet metal forming numerical simulation and developed a mesh variable mapping algorithm to address the problems in the previous analysis. Chen Jun [14] considered the influence of mold deformation and part thinning on the closing rate based on Zhang Guibao's mapping algorithm, but ignored the main factor of machine deformation. Xia Guodong [15] proposed a boundary force load mapping algorithm based on Zhang Guibao's research, which relies on commercial software to complete load mapping. Gong Zhihui [16] proposed a surface construction method that can be directly used for mold surface processing based on compensation amount of surface nodes, but the compensation value is obtained assuming the mold is rigid and does not consider the influence of mold and machine deformation on the compensation value.

In recent years, the deformation of mold surfaces has been increasingly considered during the mold design process [17-21], while the deformation of machine tools has not received particular attention. However, during the stamping process, large stamping molds are subjected to significant forces, resulting in some deformation of the machine tools. The deformation of the mold surface and machine tools can have a significant impact on the manufacturing accuracy of stamped parts, therefore it is crucial to perform structural stress and deformation analysis on stamping molds and machine tools.

In this article, finite element software ANSYS was used to compare the strain of the same set of molds assembled on different machine tools to analyze the influence of machine tool deformation on the mold surface.

2. Machine Modeling

Due to the need to consider the elastic deformation of the machine tool and its table, it is necessary to import the machine tool model during finite element analysis. Therefore, it is necessary to model and assemble the machine tool. During the field research in the factory, it was observed that the actual structure of the machine tool is that the lower table is fixed, and the upper table uses a cam mechanism to achieve vertical reciprocating motion. In the UG modeling process, the cam mechanism was simplified to a four-bar linkage mechanism based on its working principle. Since the main consideration is the influence of the upper and lower tables of the machine tool on the mold deformation, it is necessary to simplify the machine tool model, and also to reduce model size and improve the efficiency of finite element software analysis. After completing the machine tool modeling, only the lower half of the machine tool and the force-applying part of the four-bar linkage mechanism were retained, as shown in Figure 1.

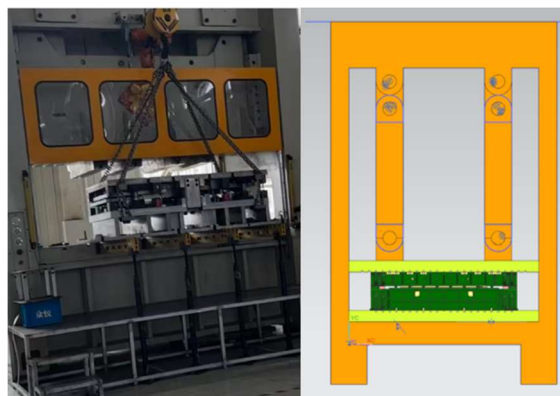


Figure 1. Machine modeling

3. Simplification of Molds

Based on the shape of the stamped parts required, the mold design was carried out. After completing the mold design, some components and structures were found to have no influence on the force transmission in the mold. Therefore, it was necessary to simplify the mold by removing some structures and standard components that did not affect force transmission, such as the piercing knife on the mold surface. As shown in Figure 2, the piercing knife is mainly used to pierce materials during the stamping process, such as piercing and removing excess materials during the stamping process, cutting products during the die-cutting process, and punching products during the die-cutting process. However, it does not affect the force transmission when the mold is under pressure, and it also increases the workload when meshing in finite element software. Therefore, the piercing knife was deleted and repaired into a module, and standard components that did not affect force transmission were merged into the upper and lower molds, ultimately simplifying the mold surface for easy meshing and finite element analysis.

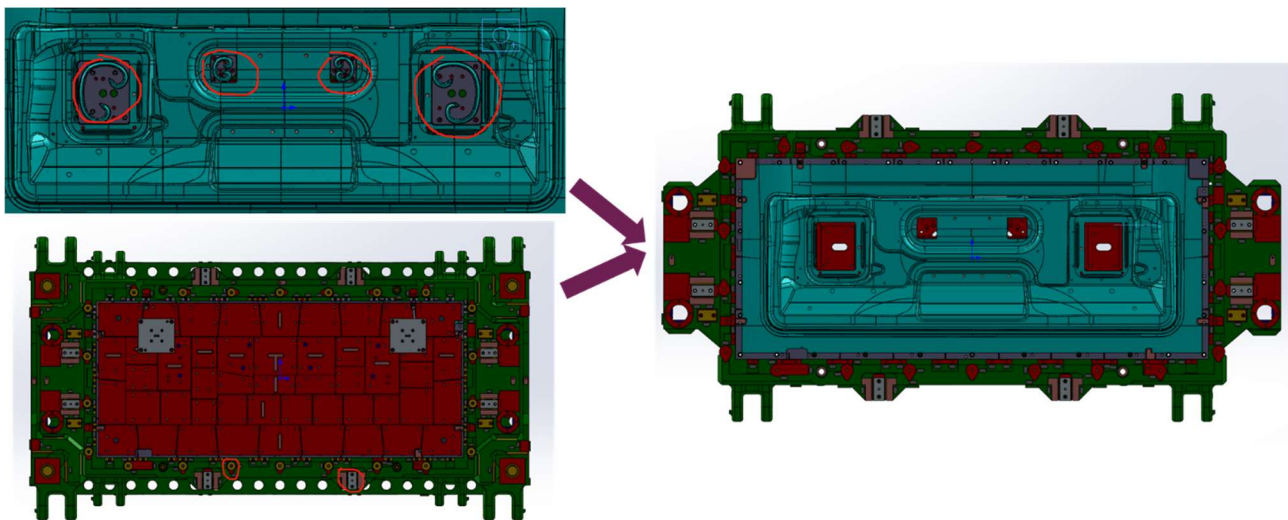


Figure 2. Simplification of molds

4. ANSYS Finite Element Analysis

The software used for the finite element analysis in this study is ANSYS Workbench. Workbench is an engineering simulation software developed by ANSYS that provides a collaborative simulation environment to assist engineers in solving the heterogeneity issues of CAE software during product development. Through Workbench, engineers can perform various types of simulation analysis on complex mechanical systems, such as structural statics, structural dynamics, fluid dynamics, and more.

The simulation process using Workbench is relatively simple. Users can import models created by mainstream CAD software for simulation analysis, set material properties, adjust simulation parameters, and more. Workbench also integrates data management and visualization tools that allow users to conveniently monitor the simulation progress, analyze simulation results, and optimize product design.

4.1 Establishment of Stamping and Forming Simulation Model

There are two ways to create a model in Workbench: the first method is to directly use the built-in preprocessor in Workbench for modeling; the second method is to create the models of the upper and lower dies, the blank holder, and the machine tool's upper and lower tables in a 3D CAD software according to the specific forming plan, and then save them as STEP or IGES file formats to import into the Workbench system. Due to the complexity of the stamping die and stamping machine tool

structure in this study, we used UG to complete the modeling of the die and machine tool as described in the previous two sections. After simplifying the die and machine tool, we assembled the die onto the simplified machine tool, saved the assembled model as a STEP file format, and then imported it into Workbench for finite element analysis.

4.2 Material Settings

Based on the actual materials of the mold and machine tool, find the corresponding materials in the material library of Workbench and set their material properties. For materials that are not available in Workbench for some components of the mold or machine tool, consult relevant data to obtain parameters such as Young's modulus and material density, and add them to the material library of Workbench. In the assembly model of this set of mold and machine tool, the material of the upper die surface is set to Cr12Mo1V (SKD11), while the materials of the upper die base, blank holder, lower die, machine tool table, etc. are set to gray (cast) iron 300 (HT300). Some of the parameters of the material are shown in Table 1 [22-24].

Table 1. Material parameters

Material	Density	Young's Modulus	Tensile Strength
SKD11	7800 kg/m ³	207 GPa	3500 MPa
HT300	7300 kg/m ³	130 GPa	300 MPa

4.3 Meshing

Using the Mesh Tool in Workbench to mesh the upper and lower dies, blank holder, and machine tool's upper and lower tables, etc. The mesh selected is tetrahedral mesh, which is convenient for calculation and saves computing time. Due to the large size of the mold model, the mesh size is set to 25mm for easy calculation. In case of mesh failure, the view can be changed to wireframe mode, and the problematic part will be displayed with a different wire frame color from the normally meshed part. Alternatively, the mesh can be checked using the mesh module in UG to identify defects in the volume or surface. UG will highlight the failed mesh part, making it easy to correct the mold. The mesh result is shown in Figure 3.

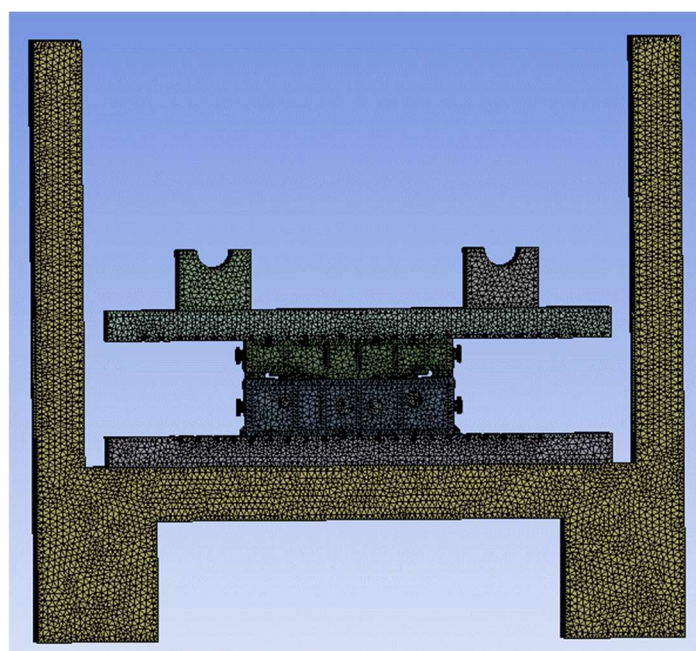


Figure 3. Meshing

4.4 Define Constraints

Set the constraints for the assembled mold on the machine tool model, based on the actual working conditions of the mold and the necessary conditions such as constraints, forces, and gravity applied to the mold and machine tool. The constraints defined for this set of mold are mainly divided into four categories:

- ① Standard gravity;
- ② A total pressure of 3000 KN is applied by the press to the upper surface, which is divided and distributed among four sets of connecting rod mechanisms.
- ③ Since the machine tool is placed on the ground, a fixed constraint is applied to the lower surface of the machine tool, limiting its freedom to zero.
- ④ The machine tool is only half of the actual machine tool, so a sectional view of half of the machine tool needs to be set up, with the freedom in the horizontal direction set to zero and only able to move in the Z direction.

The constraints are defined as shown in Figure 4.

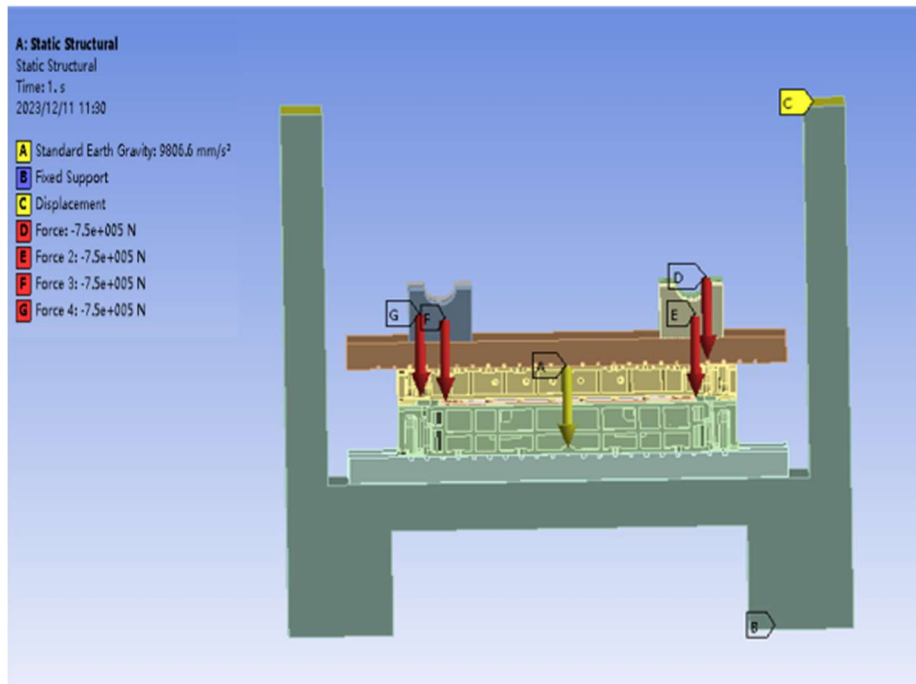


Figure 4. Constraint settings

4.5 Submit Calculations

After the above settings are completed, the solver is submitted for calculation, which calculates the total displacement and equivalent total strain of the assembled mold and machine tool under this force state.

4.6 Analysis of Results

After the calculation is completed, set the stress or strain parameters you need to view on the results page, and retrieve the desired content from the obtained results; at the same time, you can also view the dynamic evolution of the force applied to the machine tool and mold. The result of mold assembly is shown in Figure 5.

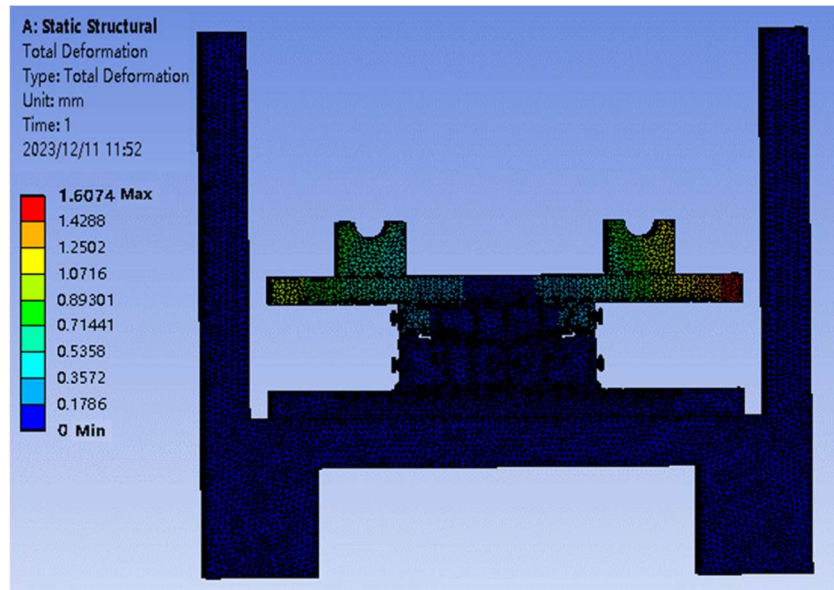


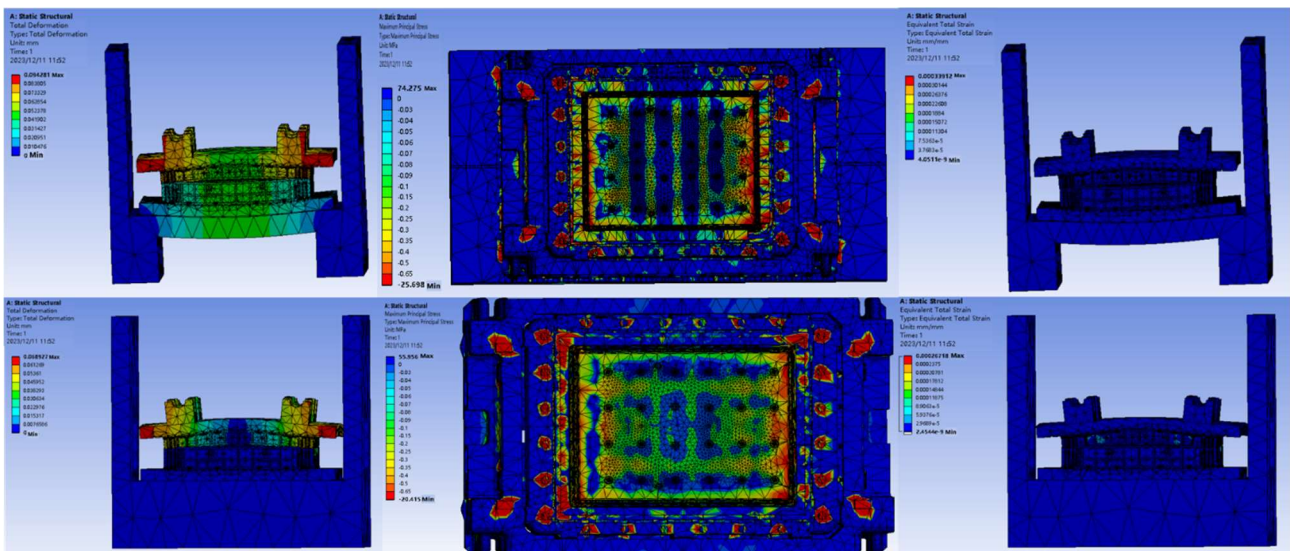
Figure 5. Assembly displacement calculation results

Figure 5 presents the displacement calculation results of the assembly, with a maximum displacement of 1.6074mm, occurring at the right upper surface. The minimum displacement is 0mm, as the bottom of the machine tool is fixed to the ground. Therefore, the minimum displacement is located at the bottom of the machine tool.

5. Comparison of Mold Deformation of Different Machine Tools

Because this article aims to explore the influence of machine tool deformation on mold surface deformation, analyzing only one set of mold assembled on one machine tool would be special and accidental. Therefore, the same mold was assembled on different machine tools for finite element analysis, and multiple sets of different mold surfaces were also analyzed. The steps of analysis, simplification, and assembly were the same as those mentioned in Section 3, with the addition of support for the lower surface of the machine tool and the mold at the original base of the machine tool.

The results obtained when three sets of molds were assembled on different machine tools are as follows:



(a)

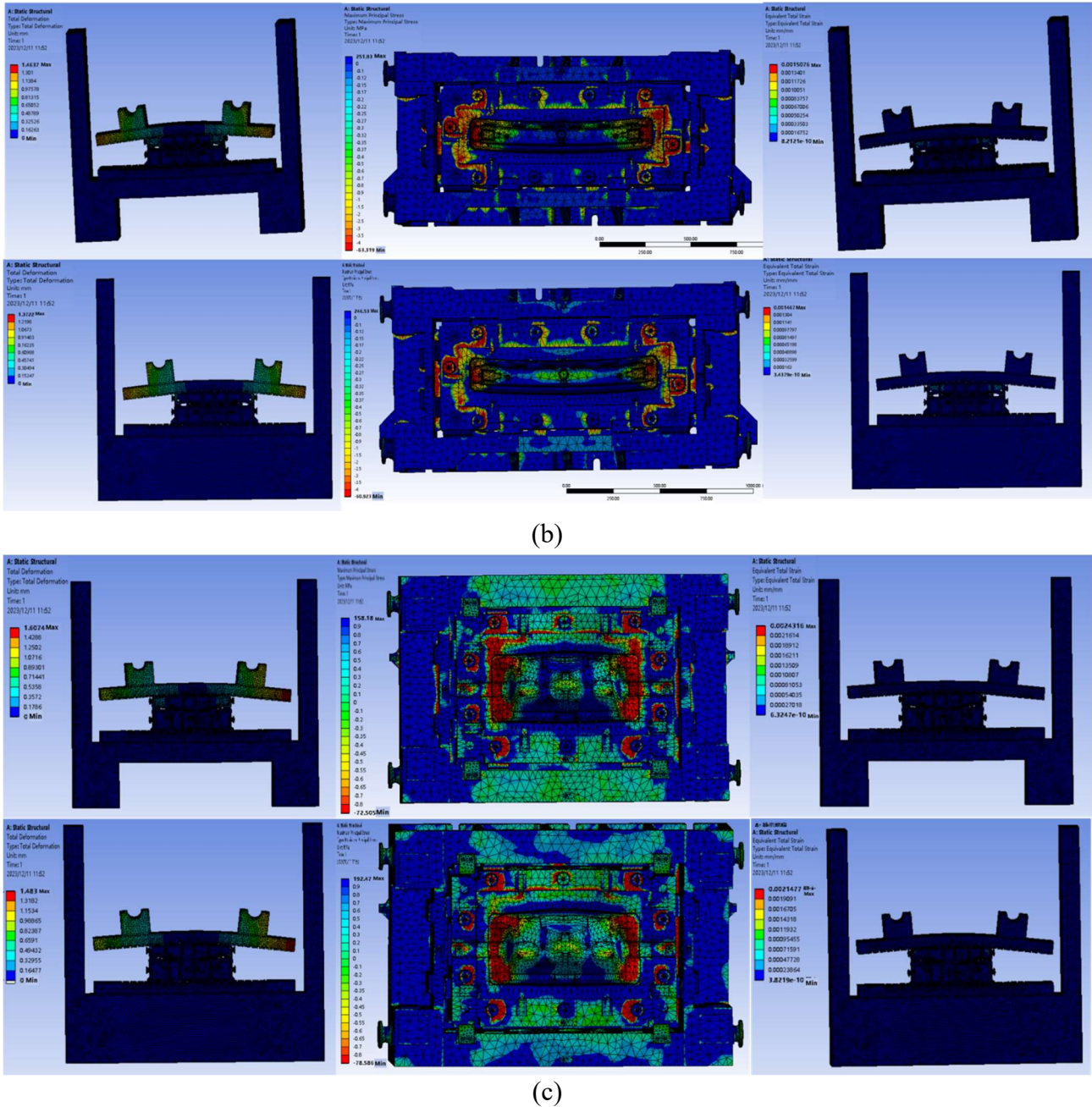


Figure 6. The finite element software calculates and analyzes the influence of the shape and structure of the machine tool

The three sets of figures a, b, and c in Figure 6 show the finite element analysis results of three different mold surfaces installed on the lightweight machine tool and the machine tool with additional support at the base, respectively. The upper and lower figures form a comparison of the same mold surface on different machine tools. In the three sets of figures, the left-to-right calculation results are the total deformation distribution of the assembly, the main stress distribution of the assembly, and the overall main strain distribution of the assembly.

Taking Figure 6a as an example, when the mold is installed on the lightweight machine tool and pressure is applied, the maximum total deformation of the mold on the lightweight machine tool at the same position of the mold surface is 0.094mm, while the main stress on the mold on the machine tool with additional support at the base is 0.069mm. The main stress of the mold on the lightweight machine tool is 0.0265MPa, while the main stress on the mold on the machine tool with additional support at the base is 0.031MPa. The overall main strain of the mold on the lightweight machine tool

is 0.00033, while the overall main strain on the mold on the machine tool with additional support at the base is 0.00036.

6. Conclusion and Prospects

6.1 Conclusion

When assembling the same mold on different machine tools, the total deformation of the machine tool and the mold, the maximum principal stress, and the equivalent total strain all differ. The more support provided for the lower surface of the machine tool, the greater the pressure on the mold surface, resulting in smaller total deformation and total strain for both the mold and the machine tool. Therefore, in order to design a fine mold surface for automotive panel molds, it is necessary to analyze each mold based on the specific machine tool it will be used on during operation. Each mold should have its own unique design plan, and the deformation of the machine tool should be considered in the compensation of the mold surface during the design stage, rather than relying on post-correction methods such as fitter corrections after the mold design is completed.

6.2 Prospect

Through this simulation study, I only compared the strain and displacement of the mold surface when the same mold is assembled on different machine tools. In addition, we can also conduct a cross-comparison to compare the deformation and displacement differences of different molds when assembled on the same machine tool, explore the compensation law of the mold surface, and improve the efficiency of mold surface compensation.

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